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A LOOK AT BEHAVIOURISM AND PERCEPTUAL CONTROL THEORY IN INTERFACE DESIGN

Sandra Chéry
Philip S.E. Farrell

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
Toronto, Ontario
Canada M3M 3B9

19980608 063

DEPARTMENT OF NATIONAL DEFENCE – CANADA

Executive Summary

Behaviourism is the study of human behaviour where individuals respond to stimuli. This paradigm does not explicitly include the purpose of human response, and claims that humans act in an automatic fashion. However, behaviourism cannot account for certain observed behaviours such as response variability, instinctive drift, autoshaping, etc.

Perceptual Control Theory (PCT) postulates that behaviours result from the control of perception. The concept of purposeful behaviour is explicit in PCT. In this view, behaviours are designed to counteract external disturbances; thus, minimising the error between the perception and its reference. Central to the theory is the concept and necessity of feedback to ensure a stable system. Furthermore, PCT claims to have answers for some of the observed behaviours mentioned above. However, one PCT difficulty is the ability to objectively measure internal perceptual variables.

These two psychological models have been applied to interface design. In a human-machine system, the behaviourist would say that the machine should display the exact stimuli needed to elicit the proper human response. In some ways, the machine is seen to control the human's behaviour. A *PCTer* sees both the human and the machine having certain information and communication needs that are required to stabilise their individual control loops. Stable loops will yield enhanced system performance and reduced workload. To this end, a task analysis, based on PCT, was proposed and presented in this report that complements and completes the entries missing in traditional task analysis tables.

The CF has benefited from Perceptual Control Theory studies. The theory was applied to the CC-130 study in developing a new curriculum for crew resource management. Work is currently under way with the redesign of the Control Display Unit of the CH-146 Griffon helicopter using the concepts of PCT interface design. In the future, the PCT task analysis will be tested against a known CF aircraft task analysis to determine the value added with this new method. If successful, this technique may be applied to a virtual interface for shipboard communications.

Abstract

Behaviourism and Perceptual Control Theory (PCT) were reviewed and their shortcomings, as well as their application to human-machine interactions, were assessed. Behaviourism, which studies only observable behaviours and discards the purpose of actions, implies that given a stimulus, one can predict the response. The PCT framework introduces the requirement for a desired perceptual state which would then be compared to its perception. Behaviours would then result in an attempt to minimise the perceptual error when present. However, PCT's difficulty includes the inability to objectively measure internal variables. Behaviourism, on the other hand, can not account for variability in responses, instinctive drift, autoshaping, etc. Researchers have used behaviourism as a framework for human-machine interactions concluding that compatibility between a stimulus and its response resulted in increased performance of the system. Other researchers have argued that the use of PCT in human-machine interactions can explicitly show all the required feedback messages necessary for a stable and effective interaction between the human and the machine.

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Table of Contents

List of Figures

Introduction

Design of interfaces in industry continues to be more of an art form than a true science. Researchers have used concepts in engineering and psychology to develop systematic ways for analysing and designing human-machine systems. While many researchers have used traditional psychological models in their study of interface design, others have used a relatively new theory in psychology called Perceptual Control Theory. A review of traditional and new theories in psychology allows us to compare the theories, identify their shortcomings, and comment on their applicability to interface design.

Psychology, etymologically speaking, is the science of the *psyche* (from the Greek word for soul or mind). Aristotle's De Anima was the first attempt at a systematic treatment of sentient or mental life. The outcome was the birth of the science of the mind which was largely speculative and philosophical.

Centuries later, behaviourists limited themselves to empirical and observable data. Behaviourists studied psychology as a science of observable comportment thereby putting more emphasis on the output of the "black box" (i.e., the mind) rather than the dynamics of the "black box" itself. The philosophy underlying behaviourism seemed to ignore the purpose behind the behaviour, thus individuals were seen to react in an automatic fashion. Given a stimulus, one could predict the response. From that, the Stimulus-Response (SR) paradigm became the mechanism underlying all learned behaviour, according to early behaviourists.

In contrast, Perceptual Control Theory (PCT) postulates that behaviour is the result of the control of perception and not simply an automatic response to a stimulus [1]. PCT exploits the concept of a purpose behind the behaviour. A perception (which is a transformation of stimuli from the world) is then compared to its reference signal, and a perceptual error is generated. A person acts on the world in such a manner to minimise this error. The stabilisation of this control loop is the essence of PCT.

Behaviourism should provide the specifications for interface design that optimises the overall system performance, since a given stimulus should evoke a repeatable response. However, observations show that this approach is limited to systems with relatively few degrees of freedom and well-controlled environments. By adopting a PCT approach, the emphasis is placed on the satisfaction of internal goal states rather than trying to explain variation in response to a given stimulus. This focuses the design of the interface towards providing pertinent information and response mechanisms to satisfy the goals.

Literature Review

Behaviourism

> *"Give me a dozen healthy infants, well-formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select - doctor, lawyer, artist, merchant-chief and, yes, even beggar-man and thief, regardless of his talents, penchants, tendencies, abilities, vocations, and race of his ancestors."* John B. Watson, 1924 [2].

John B. Watson was an American psychologist who was considered to be the father of behaviourism and introduced SR theory. Watson believed that psychology should be the study of observable behaviour, and not the study of thoughts, hidden motives, wishes and feelings that could accompany these behaviours. Watson also argued in 1913 that each individual is made, not born. He discounted the importance of genetic inheritance maintaining that behaviour is entirely governed by the environment. He believed that given the stimulus, one could predict the response as shown in Figure 1.

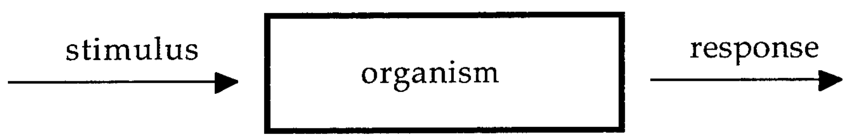

Figure 1. SR Model

Pavlov's experimental evidence of Classical Conditioning (CC) became the root of behaviourism [2]. A bell solicited the same salivation response as food because both stimuli were presented together over a period of time. The food was defined as the unconditioned stimulus (US) which evoked an instinctive response. The bell was defined as the neutral stimulus (NS) that had not been previously associated with the food-salivation pair. Once the association took place the bell was referred to as the conditioned stimulus (CS). CC is an elementary type of learning where NS is associated with US, and has acquired the ability to evoke the original response.

Pavlov identified five major conditioning processes in CC:

- <u>Acquisition</u>
  CC is biologically adaptive. It helps the organism to prepare for favourable or unfavourable events that are about to occur.
- <u>Extinction and Elimination</u>
  If US no longer occurs upon the presentation of the CS, the Conditioned Response (CR) becomes weaker with time.

- Spontaneous Recovery
  If one allows some time before presenting the CS, its CR would reappear again.
- Generalisation
  It is a tendency to respond to stimuli similar to CS.
- Discrimination
  The subject can distinguish between CS and similar, but irrelevant stimuli.

The relationship between the first three conditioning processes can be shown in the graph illustrated in Figure 2.
Pavlov's work paved the way for SR psychology since CC was considered as one way almost all organisms learn to adapt to their environment.

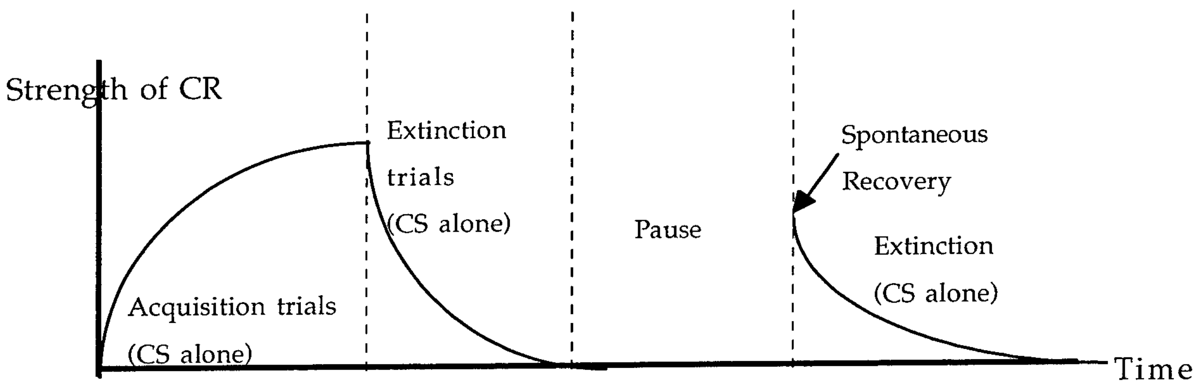

Figure 2. Processes in Classical Conditioning [2]

Burrhus F. Skinner, another behaviourist, wanted to discover the relationship between the stimulus and the response in order to describe, understand and predict behaviour [2]. He believed that organisms tended to repeat responses that led to positive outcomes and did not repeat responses that led to neutral or negative outcomes. Therefore, behaviour can be controlled by manipulating the response consequences. The basis of Skinner's work became known as Operant Conditioning (OC). OC is a type of learning in which behaviour is strengthened or diminished if followed by reinforcement or punishment, respectively. Skinner claimed that, behaviour was controlled and shaped by external influences (i.e., the environment), and not internal thoughts, feelings, or goal perceptions. He noted that OC was not the result of CC, but the result of the association between the response and the reward.

Behaviourism, to a large extent, implied that behaviour was under external control. A behaviourist might have concluded that, in a human-machine system, the machine and the environment became the provider of all necessary stimuli for the human to act, thus controlling human response.

Behaviourism in Research Applications

Behaviourism has been used as a basis for understanding human-machine interactions in many research projects. Summarised below are three representative papers that have applied SR theory to interface design.

Zhang believed that the liveware (i.e., the human) component of a system must be reflected in the interface such that the displays provide stimuli and the controls become the response mechanisms [3]. Zhang applied the SR compatibility principle developed by Fitts and Seeger (1953), who suggested that performance is optimised (i.e., reaction time is fastest and error rate lowest) when displays and controls match each other. Thus, SR compatibility does not only depend on the type of stimulus and response, but on the relationship existing between the two sets. Kornblum (1992) (cited in [3]) generalised the SR compatibility principle to situations where the stimulus and the response are similar, and their conceptual correspondence is natural and intuitive (e.g., the knob alignment on a stove reflects the positions of the stove elements). Conceptual correspondence is not restricted to SR pairing but can be extended to stimulus-stimulus (SS) pairing where two stimuli are similar (e.g., knobs on a gas stove versus the knobs on an electric stove).

In order to optimise the interface, Zhang asserted that the SR and SS compatibility must be analysed for complex tasks. It was hypothesised that SR compatibility gave rise to superior performance because the automatic and controlled processes produced consistent response codes. Conversely, the non-corresponding condition gave rise to inferior performance because the automatic and controlled processes produced different and competing code responses.

According to John et al., SR compatibility was a robust psychological phenomenon where the response difficulty depended on complex inter-stimuli relationships [4]. Thus, the complexity of the cognitive transformations made by the human operator varied directly with the complexity of the inter-stimuli relationships. Indices of difficulty were response time, numbers of errors made, learning time and preferences.

In their experiment, two abbreviation techniques were compared in an encoding task. Abbreviation techniques are mapping specifications between a set of stimuli and a set of responses. The experimental hypothesis was that people performed reaction time tasks by executing their own algorithms (or programs) for the tasks. These algorithms were based on the concepts of Goals, Operators, Methods, and Selection rules (GOMS). The GOMS model [5] is a cognitive theory which was used to quantify the level of complexity and provided a rational explanation for the reaction time differences as the SR mapping became more complex. The GOMS framework can be applied to task analysis where the analyst is concerned about goals (what the user wants to accomplish), operations (actions needed to be done), methods (sequences of operations) and selection strategies (user's knowledge of which method to apply for certain situations) [6]. An

algorithm could be written for each task and a predicted response time could be calculated from that algorithm. Algorithms would be described either by examining the behaviour of people as they perform the task or through an abstract analysis analogous to developing an algorithm for a computer program. The experimental results suggested that as the SR mapping was more complex, the abbreviation technique was also more complex.

Kantowitz and Campbell demonstrated the role of SR compatibility in the field of human factors [7], and claimed that it might predict and eventually reduce human error. Human-machine systems often demonstrate poor efficacy due to the requirements imposed on the human operator that are incompatible with the user's cognitive processing model. Wickens claimed that 60 to 90% of major accidents and incidents in complex systems such as nuclear power, process control and aviation are caused by human errors [8].

Many of these errors are the result of poor automated system design which determine the user's actions and overload human information-processing capabilities. Although the use of automation can lead to a decrease in the number or severity of traditional errors, human errors are not eliminated by automation. Wickens argued that automation "...merely relocates the sources of human error to a new level" such as incorrect entries for instance.

In this context, SR compatibility refers to the geometric as well as the conceptual aspects of the stimulus (display) and response (control action). Kantowitz and Campbell presented a model based on a nested hierarchy of frames (a well-developed structure based on the user's training and experience), rules and response tendencies as shown in Figure 3.

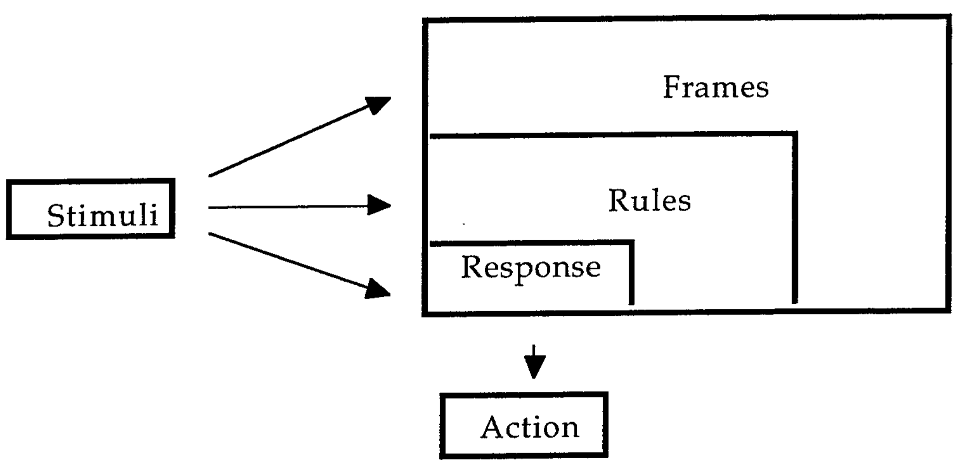

Figure 3. Recent SRC Model [7]

Kantowitz and Campbell used the aircraft flightdeck as an application of the theory. A low SR compatibility was identified as a cause to potential

flightdeck problems. Automation exhibiting low SR compatibility would confuse the pilot increasing the task effort unnecessarily. One solution was to have the original design more compatible with the pilot frames and rules. Accurate feedback was seen to be the key component in designing the system. Feedback helped the pilot understand what the automation was doing. The ability to utilise feedback was essential for human-machine systems. Thus, flightdeck displays and controls must be compatible with the pilot's interpretation of displayed information, decision-making processes and response tendencies.

Perceptual Control Theory

Perceptual Control Theory (PCT) is a new psychological framework that provides a unifying model of perception and behaviour. PCT is based on the tenet *all behaviour is the control of perception* [9]. Its basic structure is a classical control feedback loop where the perceptual signal is defined as the control variable, as opposed to the behaviour as one might interpret behaviourism to claim. PCT involves comparing a perceptual signal with a reference signal, generating a perceptual error signal. The error signal is the incoming information to the Output Function (OF) that transforms the error into certain behaviours. Behaviours act on the world and influence, what is called, the Complex Environmental Variable (CEV, which is a transformation function generating stimuli as its output [9]). Stimuli are transformed by the Perceptual Input Function (PIF) into perceptions, thus closing the loop as shown in Figure 4.

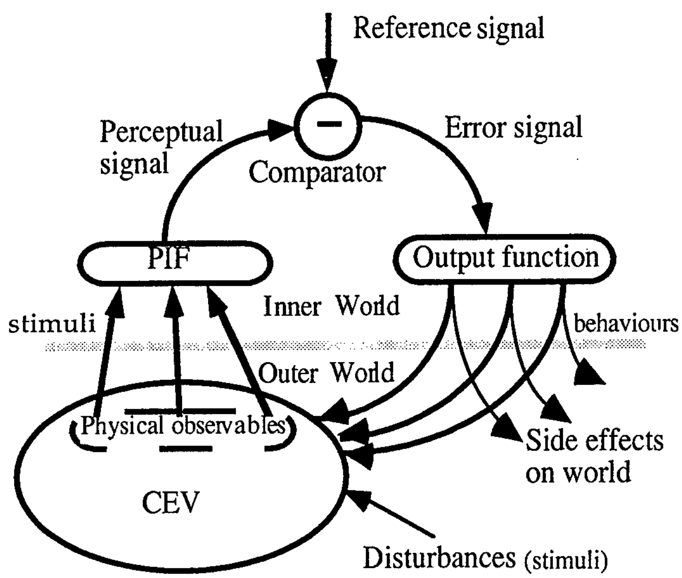

Figure 4. A closed loop representation of the control of a perception defined as an Elementary Control Unit in PCT: the Perceptual Input Function (PIF), Complex Environmental Variable (CEV), and the Output Function represent signal transformations around the loop [9]

Classical control theory would state that when the perception converges to the reference signal the loop has settled. Moreover, an unstable loop may require

the adaptation of the transformation functions around the loop in order to stabilise the human-world system.

Powers believed that a reference signal is a perceptual condition from the subject's point of view (not the experimenter) that calls for no effort [1]. It is not an entity directly observable. It is the goal, the intention or desired state that organisms want to maintain under control. Errors are always corrected with respect to a reference condition which is understood, translated into specifics, and maintained inside the individual. The person can be said to control their perceptions if any disturbance that would normally cause a deviation from the reference perception evokes a behaviour that rejects the disturbance.

Having the core tenet in mind, PCT postulates that the only reason for which any higher organism acts is to counteract the effects of disturbances (constant or varying) on controlled quantities it senses. When the nature of these controlled quantities is known together with the corresponding reference conditions, Powers would claim that the variability of behaviour is predictable.

However, a perception does not cause a behaviour directly. It is only the difference, if any, between the perception and its reference condition that warrants an overt response. Also, it is not the actual stimuli that lead to responses (as behaviourism would imply). There are transformations between the stimulus and the response that involve the interpretation of stimuli and the design of a response by the organism [10].

But how do new control systems develop? Powers' model postulated that error conditions within the system of an organism must result in increased neural firing throughout its nervous system. When an intrinsic system error condition leads to a general neural firing in the brain, it results in movements which are random until a reduction of intrinsic error occurs. Then, the organising/reorganising system shuts down, the current configuration of neural circuitry is kept and a behaviour is adopted. Eventually, when these intrinsic system errors decrease, the neural circuit active at that time becomes a new control system to counteract such errors in the future. The new circuit is a control system for the disturbance which initiated the error condition. Generally, the PCT model adopts a hierarchical arrangement that connects lower to higher level control loops. Learning is considered to be the act of reorganising the structure.

PCT in Research Applications

Bourbon et al. agreed that Control System Theory (CST) provided a good model of human behaviour because it includes negative feedback necessary for the control of perceptions [11]. CST was used to produce detailed quantitative, accurate and reliable predictions of people's responses to their environment.

Bourbon performed an experiment that involved tracking a computer-generated target with a cursor. The target was changing position at a constant

speed and subjects had to align, with the help of their handles, the cursor to the target on their screen. This experimental data was collected and compared with the predictive results obtained using CST for the same task. The correlations between predicted and actual positions typically ranged between 0.980 and 0.997. Their results suggest that whether the path of the target was predictable (condition 1) or randomly unpredictable (condition 2), CST can provide strong predictions about human behaviour for pursuit tracking tasks.

Bourbon also predicts that "...when we know the perception a person is controlling (...) the PCT model predicts actions as accurately five years in advance as it does across a few minutes or a year" [12]. In July 1993, he completed the same experiment as in June 1988 (see experiment above) where correlations between predicted and actual positions were 0.998 for condition 1 and 0.997 for condition 2.

In the tracking task, a person must have a desired state of variables in the environment, perceive that current state, and have the means to affect at least some of the perceived variables by acting in the environment. The intent is to minimise the difference between the current and desired states. Bourbon suggested that PCT could provide an explanation for the way people achieve consistent results in a variable world.

Farrell and Semprie applied PCT to develop a new human-machine interface for CH 146 helicopter pilots [13]. The analysis was based on Layered Protocol Theory (LPT) [9,14]; a special form of PCT illustrating interactions between two communicating partners. They argued that a design based on PCT ensured that the interface focused on the user's perceptions (as opposed to the user's actions). The identification of the perceptual error led to the design of behaviours intended to minimise the error. Further studies will determine the effectiveness of designing interfaces using LPT methods.

Discussion

Behaviourism Shortcomings

Most psychologists agree that behaviourism is and should be an objective science but many disagree that it should consider only overt behaviour and not the cognitive structure itself [2,15]. Pure behaviourists would treat stimulus and response as cause and effect and all that lies between as an automatic machine having properties but no purpose.

A drawback of behaviourism is that the concept of association is limited when relating connections that occur in learning with the nervous system [15]. Every idea or act is taken as a unit by itself and this has created considerable confusion in attempts to get an explanation of how association works. One learning theorist, Guthrie in 1935, proposed that all signals flowing simultaneously in the sense receptor became associated with each other (cited in [16]). Pavlov in 1957 and others believed that associations were formed only between sensations which immediately preceded a built-in (instinctive) reflex such as salivating at the sight and smell of food (cited in [16]).

Another difficulty of this theory is that a stimulus may not produce an identical, repeatable response as behaviourists presumed. Behaviourists ascribed behaviour unpredictability to a common property of all living organisms: variability. Variability explained the inability to control the same stimuli given to an organism in every instance. PCT on the other hand offers a valid explanation for behavioural variability. In a PCT framework, one cannot presume the reference value to be fixed or unconstrained by changes due to the influences of higher level loops. Individuals can have different goals from instances to instances which remain unseen for an external observer. Thus, for a given perception needed to be controlled, x amount of behaviours have the possibility of being observed since x amount of reference signals have the possibility of being controlled. By the same token, x perceptions can lead to a single behaviour. The key concept to understand is that a stimulus produces different behaviours because the reference value which is controlled differs in every eventuality.

Also, behaviourism fails to explain the following common behaviours [16]:

- <u>Instinctive drift</u>. Animals trained by Operant conditioning fail to continue to display conditioned response on cue. Instead, they drift toward species-specific, instinctive behaviour. A PCT explanation might be that the introduction of a conditioned response may produce side effects (see Figure 4) that upset the natural balance of other important perceptions. Therefore, the PCT model would act to stabilise these other loops. Thus, the behaviour would drift towards more instinctive behaviour being defined as a region of global stability rather than local stability.

- Autoshaping. Animals appear to learn without reinforcement. However, conditioning theory speculates that learning results only when reinforcement is present. It has been rationalised by saying that the reinforcement must be internal to the organism. Nevertheless, this explanation is a violation of the behaviourist paradigm which states that only externally observable actions are appropriate for psychology. PCT would explain autoshaping as the need to control a new perception which may result from imagination, experience, or learning.
- Biological constraints. This term covers the whole range of innate knowledge which different species seem to have about what is and is not good for them. This is related to the instinctive behaviour discussed above. Instinctive behaviour might be described as a PCT loop that has been optimised, and now requires a lot of effort to change, even for a short duration of time.
- Insight. This is a perception of relationships between phenomena or facts that were not previously seen as related. PCT has the mechanism of imagination that may provide insight. However, neither PCT nor behaviourism has strong models for pure inspiration.

PCT Shortcomings

Behaviour being the result of the control of perception implies that the control is intrinsic to every individual. Therefore, an external observer can not explicitly determine an individual's perception being controlled and its value. This aspect of PCT makes the model difficult to determine precisely. Recall that behaviour is governed by the error generated by the internal reference and the perception. While an external observer may have some influence over what sensory information the subject perceives, he does not have any influence over the internal reference signal.

PCT models are hierarchical in nature, and the number of levels to be modelled is potentially large. A cognitive scientist might be interested in the higher abstraction levels of reasoning and logic. A designer would only be interested in those intermediate levels that effect interface design. Perhaps the physicist is only concerned with the atomic and sub-atomic levels. The theory provides little guidance to the granularity of levels that are appropriate for a particular system analysis.

Elements of Behaviourism in PCT

The perspective in which one views the organism is conceptually different depending on whether one views it from a behaviourist or PCT paradigm. Behaviourism emphasises the beginning and the end of events while PCT demonstrates explicitly the purposive attribute of events. However, this review has suggested that one can find common ground between the two theories.

Some behaviourists have realised the importance of feedback in an SR mechanism the same way Skinner did in his model of Operant behaviour. Hebb

(1964) claimed that "... any behavioural response to a single stimulation thus produces a sensory feedback which can act as the initiator of a second response whose feedback initiates a third response and so on". Feedback here is seen as the effects of behaviour in altering subsequent stimuli in a series of discrete, well-separated responses alternating with discrete stimuli. Moreover, Powers clearly states that SR laws are predictable within a PCT model [1]. The SR paradigm might describe human behaviour from an external observer's point of view while PCT may be a description of human behaviour from the organism's point of view.

Even with the addition of a feedback loop in behaviourism, the PCT reference signal can not be explained with the SR model, and it becomes a fundamental difference between the two theories. Another difference between PCT and SR lies within the effect of a stimulus on the model. For PCT, the stimulus affects the perceptual signals. For SR, the stimulus directly affects behaviour. Thus, PCT allows for the situation where a stimulus is present but no behaviour takes place, and vice-versa, while in SR, no stimulus necessarily means no response.

Powers believes that PCT and SR paradigms are fundamentally incompatible and that if one is right, the other must be wrong. PCT attempts to explain every component and step involved in behaviour. SR does not seem to be an incompatible model but simply lacks in specifics. Although behaviourists claim that a stimulus produces a behaviour, experience and common sense dictate that actions have intentions underlying them as well. Thus, goals are important to human behaviour.

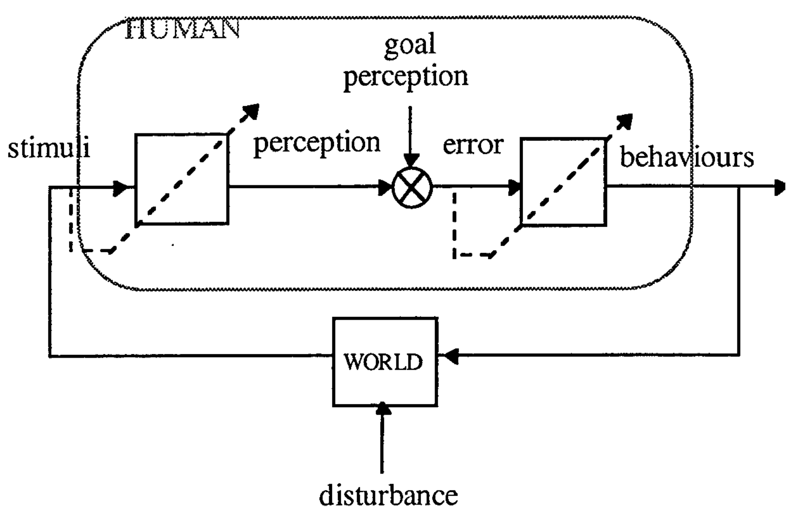

Figure 5. A Diagrammatic View of SR Models within PCT

Figure 5 shows the relationship between behaviourism (classical and Operant conditioning) and PCT. While Classical Conditioning (CC) and Operant Conditioning (OC) attempted to explain learning and the way behaviours adapt

to their environment, PCT combines learning and interaction processes into a single model. CC is explicit in the figure where stimuli are perceived by the human and behaviours consequently result. Also, OC is made obvious where behaviours act on the world generating stimuli and then perceptions (e.g., rewards and punishments) which, when different from the goal perception, can be used to shape behaviours (i.e. the dotted lines). The interaction process is illustrated as a feedback loop between the human and the world in an attempt to minimise the perceptual error.

Potential Analysis with Behaviourism and PCT

The PCT model illustrates how humans behave controlling their perceptions. A machine's responses can also be depicted by analysing its perceptual signals and by assuming the goals that had to be implemented by its designer. Both entities's behaviours then become predictable and performance of the system can be enhanced. The interface linking the human and the machine can then be optimally designed since one can foresee the partner's reactions to a particular perceptual change. Once one knows the goal and the perception being controlled, the interface can be designed in such ways to allow the user to minimise the perceptual error leading to the design of a response. The advantage of PCT in interface design is that the human, the machine and the interface are made explicit in the model. Also, since the model is based on Control System Theory (CST), the functions and signals of the model should be predictable using CST analytical techniques.

Human-machine systems are usually depicted with an SR model of the human connected in a loop with the machine [8, 17, 18]. This approach might be more appropriate when the degrees of freedom of the system are low and the environment restrictive. In such controlled conditions, one would be able to predict a certain response given a particular stimulus since response variations are quite limited. For instance, a machine-machine system in a well-known environment may be made to fit a behaviourist paradigm with ease while a PCT description may be not necessary given the simplicity of the system.

Behaviourism and PCT in Task Analysis

Task analysis is the primary tool for the human factors specialist. It is the identification and description of work items (to be) performed by the human during a given mission scenario [19, 20]. Task analysis is important to the design process in that it feeds activities such as concept definition and demonstration, system design and development, and support and logistics design.

Task analysis has been used in a variety of applications. Each application seems to generate a slightly different way of organising the work items based on a theory or on an appropriate presentation for that application. In the methods reviewed, task analysis and its variants treat the human as an SR component within the system. The stimulus is an externally triggered

event and the response is what humans do (i.e., make decisions and act on the world).

Typically, task analyses are organised in a tabular form with the following columns: trigger event, displays, inputs, decisions, outputs, controls, and feedback [20]. However, PCT addresses these elements of task analysis. Trigger events, displays, and controls correspond to the disturbances and the CEV within the world (see Figure 4). Inputs are represented as sensory information going into the PIF. Decisions are formulated within the OF. Outputs correspond to behaviours. Feedback is part of the loop. Other task analysis methods (e.g., STANAG 3994 and US MIL-STD-46855) emphasise the hierarchical nature of tasks [20]. The PCT hierarchy maps well unto these task analysis concepts.

Cognitive task analysis attempts to decompose the cognitive activities as done with traditional task analysis. Cognitive tasks would include perceiving (sensory information and the PIF), remembering (stored reference signals), imagining (imagination loop), conceiving (adaptation and exploration), judging (comparator), and reasoning (higher levels). Each concept has a counterpart within PCT (as noted in the brackets).

The GOMS [5] approach to task analysis emphasises system goals from an external point of view. PCT refers to goal achievement from both the operator's and the machine's perspective (Layered Protocol Theory). If task analyses were developed using the PCT paradigm, the resultant list of tasks would reflect what a (potential) user employs and not what has been legislated by some external agent.

Unlike traditional task analysis, PCT also addresses the notion of side effects. That is, some tasks may affect other systems that are distantly related to the current system under examination. These side effects may have positive or negative consequences that may affect the completion of the mission. For example, generating large electronic documents may be necessary for reporting large task analyses. Such a document may place unforeseen demands on the computer's memory. The computer may crash without saving the document, and the original mission would not be achieved due to this side effect. Side effects may be identified and avoided by answering the questions, "Does this task affect other systems? If so, how?"

A PCT approach to task analysis captures all the elements of traditional task analysis. Furthermore, PCT seems to be a unifying framework for all variants of task analysis. A PCT task analysis would force the analyst to adopt an ego-centric view point. Side effects can be addressed in a PCT approach to task analysis. Finally, PCT brings back into balance the person (cognitive task analysis and GOMS) and the machine (traditional task analysis and system-based approaches) by considering the goals, perceptions, and behaviours of both partners.

Marken presented a framework for task analysis using PCT called PERceptual COntroL Analysis of Tasks (PERCOLATe) [21]. The operator is considered to be a perceptual controller. Listed below are two tables that may be representative of a PCT task analysis approach. In essence, the elements around an Elementary Control Unit can be identified and placed as headings for the tables' columns. Note that the second table is a *task analysis* from the machine's perspective. Once the analysis is complete the displays and controls columns in both tables should mesh and become the requirements for the interface design.

Table 1. PCT Task Analysis from Operator's Perspective

	required displays	data (initial or feedback)	cognitive integration activities	current user state	goal state	state discre-pancy	decisions (based on error)	tasks behaviours & side effects	required controls
level 1 . . . level 1.1 . . .									

Table 2. PCT Task Analysis from Machine's Perspective

	provided controls (sensors)	data (initial or feedback)	information integration routines	current machine state	goal state	state discre-pancy	output algorithms	machine response	provided displays
level 1 . . . level 1.1 . . .									

The tables provide insight into other design options. For example, the machine's sensors retrieve data from the outside world. It does not necessarily know the origin of the information. It may come from the operator or another machine. One might envision task analyses that show interactions for multiple agents, and the displays and controls columns connect the models together.

Conclusions

Behaviourism was summarised as the science of observable behaviour where a stimulus evokes a particular response and these two are linked through association. Several shortcomings were identified in behaviourism such as its inability to explain variability in behaviour, the concept of association, its neglect of internal/cognitive states underlying behaviour, instinctive drift, autoshaping, biological constraints, and insight.

Several researchers have applied behaviourism as a framework for interface design. Using the rationale of the Stimulus-Response Compatibility paradigm, better performance can be achieved in a system by designing stimuli (displays) that are compatible with their responses (controls).

PCT claims that the purpose of any behaviour is to drive the perception towards its goal. The main difficulty of this paradigm is that the signals within the PCT framework are known only to the individual operator. An external observer can only make assumptions about the goals and perceptions being controlled.

Researchers modelling human-machine interaction with PCT postulate that PCT-based interface designs ensure that all the required messages are made available to both the machine and the user. The interaction can be optimally depicted since both partners' goals are made explicit and compensatory behaviour is prescribed by the perceptions one partner wants to control.

PCT offers a design framework toward the satisfaction of the user's desired percepts. Human-machine system performance is enhanced when the displays and controls are designed to allow the operator to perceive and transmit information in order to minimise the perceptual error. The theory brings together the major ideas in traditional task analysis and its variants. It compliments the ecological as well as cognitive approaches to design. A PCT task analysis approach would equally emphasise goals, perceptions, as well as tasks for both the operator and the machine. Also, this approach requires the analyst/designer to take an ego-centric view of the human-machine system.

PCT offers another view point in human information processing models that can be more than beneficial in several fields such as aviation, nuclear power plant, and other engineering psychology-related domains. It is the intention, now, to apply these theoretical constructs to real world environments.

The CF has benefited from Perceptual Control Theory studies. The theory was applied to the CC-130 study in developing a new curriculum for crew resource management. Work is currently under way with the redesign of the Control Display Unit of the CH-146 Griffon helicopter using the

concepts of PCT interface design. In the future, the PCT task analysis will be tested against a known CF aircraft task analysis to determine the value added with this new method. If successful, this technique may be applied to a virtual interface for shipboard communications.

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Behaviourism and Perceptual Control Theory (PCT) were reviewed and their shortfalls, as well as their application to human-machine interactions, were assessed. Behaviourism, which studies only observable behaviours and discards the purpose of actions, implies that given a stimulus, one can predict the response. The PCT framework introduces the requirement for a desired perceptual state which would then be compared to its perception. Behaviours would then result in an attempt to minimise the perceptual error when present. However, PCT's shortfall includes the inability to objectively measure internal variables. Behaviourism, on the other hand, can not account for variability in responses, instinctive drift, autoshaping, etc. Researchers have used behaviourism as a framework for human-machine interactions concluding that compatibility between a stimulus and its response resulted in increased performance of the system. Other researchers have argued that the use of PCT in human-machine interactions can explicitly show all the required feedback messages necessary for a stable and effective interaction between the human and the machine.

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